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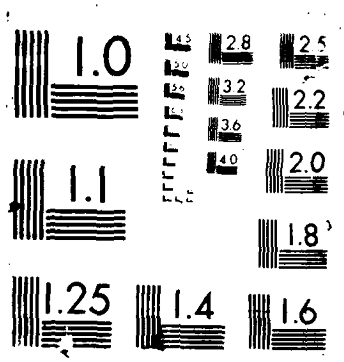
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One set of technical issues concerns implementation of map-to-image correspondence for various reconnaissance sensors including conventional mapping and reconnaissance cameras and synthetic aperture radar (SAR) systems. Here, a deterministic approach is used to implement geometric constraints based on rigorous sensor models, routine recovery of acquisition parameters and three-dimensional digital map data. This is a general approach which

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A second set of issues centers on adequate knowledge representation to support a generate-and-test strategy based on prediction of plausible signals for anticipated terrain features and objects in the absence of significant change. In this case, a family of frame-based systems are proposed to capture shallow, but critical, representations of knowledge concerning the digital map, terrain components, sensor and mission parameters.

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AUTOMATED SCREENING OF RECONNAISSANCE IMAGERY (U)

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SIGNIFICANCE OF AUTOMATED SCREENING

Automated analysis of remotely sensed imagery represents an elusive goal that has been pursued by many for two decades. The motivation for extensive research activity in both the military and civil sectors is obvious. Since World War II, there has been tremendous progress in the development of diverse image acquisition systems now flown on a variety of airborne and spaceborne platforms. The civil National High Altitude (aerial photography) Program and the National (radar) Mapping Program managed by the U.S. Geological Survey and the NASA Lunar Mapping, Landsat, Shuttle Imaging Radar and Large Format Camera Programs provide good illustrations of the diversity and capabilities of modern mapping and reconnaissance systems. Simply stated, considerable technological success in fielding image acquisition systems has led to an abundance of image data which far surpasses existing or planned image exploitation capabilities in both the civil and military sectors.

This problem has grown dramatically with the successful development of electronic imaging systems with capabilities to transmit image data in real-time to ground receiving stations. Unclassified meteorological and earth resources satellite systems, for example, operate in the visible, near-infrared, thermal-infrared and microwave regions of the spectrum, often as multichannel, multispectral imaging systems. Such systems create new opportunities for near-real-time image exploitation. These systems have also increased the volume of acquired imagery dramatically; moreover, the perishability of much of this data introduces serious time constraints which add another dimension to the image exploitation dilemma.

In almost all significant problem domains, human image interpretation techniques currently represent the state-of-the-art for extracting useful information from image data. Given the growing abundance of image data, however, few have advocated significant expansion of existing manual image interpretation staffs. On the other hand, the emergence of the digital computer led to significant investments in earth resources, mapping and military reconnaissance research programs in pursuit of automated image interpretation capabilities. After twenty years of research activity, the results of these efforts can be characterized as occasionally demonstrating partial success in limited problem domains under restricted conditions. It is the premise of this paper that automated image interpretation research has been driven by ambitious objectives that have consistently underestimated the difficulty of the problem; further most efforts have emphasized the extension of fragile methods to large volumes of diverse image data that is both highly variable and complex. Clearly, new approaches are required.

An alternative strategy is to pursue opportunities to enhance the productivity of human image interpretation specialists. One approach, the development of computer-assisted interpretation techniques to aid the image analyst directly, represents a significant objective of the research and development program at USAETL in support of the Field Army and the Defense Mapping Agency (8). A second approach is to pursue the development of automated techniques with limited goals to reduce or prioritize the volume of imagery presented to the human analyst. This process is termed automated screening.

Ideally, an automated image screening process tailored to a specific application would detect and rank all significant components in a set of imagery for subsequent analysis by a domain specialist. The value of the concept is that far less capable performance can be of considerable benefit. An automated screening process that would reliably eliminate some significant fraction of the image inventory from further analysis would have immediate and profound operational impact. This is a non-trivial objective, but one that is far less demanding than the goal to fully automate the image interpretation process which has dominated past efforts.

The sections that follow introduce two well-known approaches to the automated screening problem, image-to-image comparison and statistical pattern recognition, and suggest inherent limitations in each technique as applied to reconnaissance imagery. Opportunities to simplify the problem based on exploitation of digital terrain and intelligence data will then be introduced. Ongoing research to explore these opportunities emphasizing the concept of map-to-image correspondence and explicit representation of map, terrain, sensor and mission knowledge will be presented. General trends relevant to this problem will be reviewed and selected management issues will be highlighted.

TYPICAL APPROACHES TO IMAGE SCREENING

Research in automated screening has been dominated by approaches grounded in image processing and statistical pattern recognition based on techniques that have been successfully applied to other, less demanding tasks. Both share the characteristic and limitation of operating on two-dimensional image data without considering the inherent three-dimensional geometry of the scene and the imaging geometry of the sensor.

Image-to-Image Comparison

The well-known image processing approach to automated image screening is change detection based on direct comparison of a new image with a previously acquired reference image. The assumption is that precise registration of two digital images, picture element (pixel) for picture element, will permit the simple substraction of one image from the other to create a new image where only the changes are evident.

Considerable effort has been directed towards the development of effective image registration techniques (2,3). Although computationally intensive, these techniques are well-suited for implementation on special-purpose hardware or parallel processors. Good performance has been demonstrated as long as the inherent two-dimensional image assumptions are not stressed; this is the case if both images are obtained by the same sensor from the same approximate position and orientation such as Landsat multispectral imagery, or in the special case of flat terrain. In general, military reconnaissance and mapping applications are far more demanding where the analysis of diverse imagery acquired by many different sensors operating from a variety of platforms with a wide range of viewpoints is the norm.

Under such conditions, obtaining precise correspondence between two dissimilar digital images is difficult at best. Modest errors in geometric registration generate many "false alarms" which degrade performance and lead to requirements for considerable post-processing. Even in ideal cases, the approach is highly vulnerable to temporal variability. Natural changes in scene illumination, soil moisture, snow cover or natural vegetation state are detected which are often irrelevant to specific interpretation tasks.

Statistical Pattern Recognition

Application of statistical pattern recognition techniques to image data is also well-known (4,14) and extensively investigated. A problem-specific feature extraction process is required to represent each picture element in an image by a set of measurements, often multispectral or intensity/texture measures, as a multi-dimensional feature vector. In some mathematical fashion, the multi-dimensional feature space is partitioned to uniquely represent the set of classes to be identified. Any unknown feature vector can be assigned to the class corresponding to its position in feature space.

Statistical pattern recognition approaches have proven to be very useful in applied tasks where a stable, well-behaved feature space can be established and effectively partitioned. Considerable success has been demonstrated in some highly constrained two-dimensional industrial inspection problems and several products are commercially available. Automated analysis of reconnaissance and mapping imagery, however, has met with little success with the notable exception of automated cloud screening (7), a relatively simple problem.

The difficulties stem from the complexity and variability of both the terrain and objects operating on the terrain. Sources of temporal variability noted previously with regard to image-to-image comparison also degrade the performance of pattern recognition algorithms. Shadows, differential illumination and a variety of other diurnal, seasonal and aperiodic phenomenon all contribute to terrain variability. Identification of three-dimensional targets on the terrain is complicated by differential scale, variable aspect and rotation introduced by the wide range imaging conditions that characterize two-dimensional reconnaissance imagery. Finally, targets are embedded, often partially obscured, within the terrain background. In the past, system designers have often treated target detection as a "signal-to-noise" problem where the terrain background has been modeled simply as undifferentiated "clutter."

APPROACHES TO SIMPLIFY THE PROBLEM

When the techniques of image-to-image comparison and statistical pattern recognition were initially investigated for automated screening of digital imagery, they appeared to be sophisticated processes. In retrospect, they can now be characterized as simple approaches to a complex set of problems. Additional sources of information are needed to constrain and simplify these tasks. Fortunately, a number of new opportunities can be considered based on the availability of digital map data, the exploitation of analytical sensor models and the concept of map-to-image correspondence (8,9).

Map-to-Image Correspondence

Analytical techniques developed to support the generation of digital map data from stereoscopic imagery can be exploited to automatically project previously compiled digital map data into reconnaissance imagery.

Photogrammetrists refer to this operation as projection; computer vision researchers have adopted the term map-to-image correspondence. Prerequisites for map-to-image correspondence include an analytical sensor model for the imaging system, routine recovery of image acquisition parameters and the availability of three-dimensional digital map data.

In conventional mapping practice, use of sensor models and recovery of the image acquisition parameters are routine prerequisites to stereo mapping compilation or precise point positioning. Additionally, these procedures provide a rigorous basis for automatic prediction of precise image coordinates corresponding to terrestrial objects described by three-dimensional ground coordinates as a basis for map-guided scene analysis.

Sensor Model

Mathematical models have been developed for mapping and reconnaissance sensors which analytically characterize the image forming geometry of each system. Essentially, the simple mathematical model of the idealized "pinhole" camera has been generalized and extended to a variety of operational frame and dynamic imaging devices. Non-perspective imaging geometries, particularly the range imaging geometry of synthetic aperture radar, have also been successfully modeled (12,13).

Recovery of Acquisition Parameters

For a given image or set of images, recovery of image acquisition parameters which characterize the position and attitude of the sensor during the imaging event is a standard photogrammetric or radargrammetric operation. These procedures are described as block adjustment or triangulation when performed on multiple images and as the resection of a single image.

The development of improved capabilities for monitoring the position and attitude of acquisition platforms including inertial navigation technology and the Global Positioning Satellite system provide new opportunities to derive initial estimates of image acquisition parameters automatically.

Digital Map Data

Generation, management and exploitation of digital map data is the major focus of mapping research and development in the world leading to the production and use of digital elevation models (DEM) and digital planimetric or feature data. Digital elevation data is inherently three-dimensional as required for map-to-image correspondence. Existing planimetric data has been largely derived from two-dimensional manuscripts; however, three-dimensional planimetry can be generated by interpolating elevation values from the corresponding DEM. In the future, direct data capture of three-dimensional planimetry from stereoscopic aerial photography using analytical plotters (8) will become increasingly common providing increased photo interpreter productivity and improved metric accuracy.

Map-Guided Scene Analysis

In the near-term, the most valuable use of map-to-image correspondence may lie in the elimination of areas from manual image exploitation based terrain characteristics and military doctrine. Interactive digital image exploitation in particular, supports and requires careful management of image exploitation assignments to maximize interpreter throughput. In the long run, several more challenging tasks can be considered based on direct utilization of digital map data to support automated image analysis.

A digital map encodes an explicit model of the shape and composition of the terrain that enables map-guided analysis of the general landscape. In the context of mapping and terrain analysis, this suggests the potential for automated screening to detect changes in terrain patterns, such as those introduced by road building, land clearing or military operations, given knowledge of the previous conditions. Similarly, automated target recognition can be pursued given an explicit characterization of the terrain background rather than some generalized description of background "clutter."

In the context of automated target recognition, digital map and collateral intelligence data can be used to specify where to look for individual objects or classes of objects. Automatically searching for vehicles on or adjacent to roads, bridging operations on or adjacent to rivers, or monitoring activity at motor pools and depots, represent challenging, but constrained, localized scene analysis tasks.

Geometric constraints can be exploited in other ways to support automated analysis of three-dimensional objects. Scale, aspect, relief displacement or layover, illumination and shadows can all be predicted for terrestrial objects given knowledge of the sensor, acquisition parameters and terrain. In some instances, such as road-bound vehicles or docked boats, rotation uncertainty can be reduced to one or two orientations. Such mensuration tools represent some of the analytical processes necessary to adequately interpret the two-dimensional data recorded in images of three-dimensional objects.

AN EXPERIMENTAL RESEARCH PROGRAM

Concepts of map-guided scene analysis for automated screening of diverse mapping and reconnaissance imagery based on map-to-image correspondence are being explored by the author in an in-house research study at the USAETL Research Institute. The study focuses on a European test-site situated west of the city of Freiburg and east of the Rhine River in southwestern West Germany. The area is characterized by diverse land use and is the object of several ongoing remote sensing research programs. A diverse set of digital map and image data has been assembled.

Digital Map Data

Selected digital map overlays were extracted from the German 1:50,000 map sheets which serve as the NATO standard topographic maps for the area. These planimetric files were transformed from two-dimensional to three-dimensional coordinate data representations based planimetric augmentation using a corresponding digital elevation model. A plot of the digital data compiled in the transportation map including roads, railroads, canals and powerlines is shown in Figure 1.

Image Data

A time sequence of aerial photography obtained with conventional frame cameras has been assembled representing several film types and a range of photo scales. Space photography of the testsite was initially acquired from the Space Shuttle using the European Space Agency (ESA) Metric Camera (Freiburg was obscured by cloud cover) and later with the NASA Large Format Camera (cloud-free stereo coverage was obtained). A scanning microdensitometer at USAETL is used to convert film duplication imagery into digital data.

Synthetic aperture radar (SAR) imagery has been obtained over the Freiburg testsite during several international experiments. In July 1981, the ESA SAR 580 Campaign made an extensive set of digital SAR acquisitions. This study uses a digital X-band imagery acquired with a nominal ground resolution of 3 meters as an example of airborne SAR imagery (see Figure 2). In October 1984, the site was imaged from space during the Shuttle Imaging Radar Experiment (SIR-B). Two digital images acquired during this mission at a nominal ground resolution of 25 meters provide experimental spaceborne SAR imagery. Recently, additional SAR imagery of the testsite has been acquired by the Intera Corporation using the airborne STAR-1 X-band system.

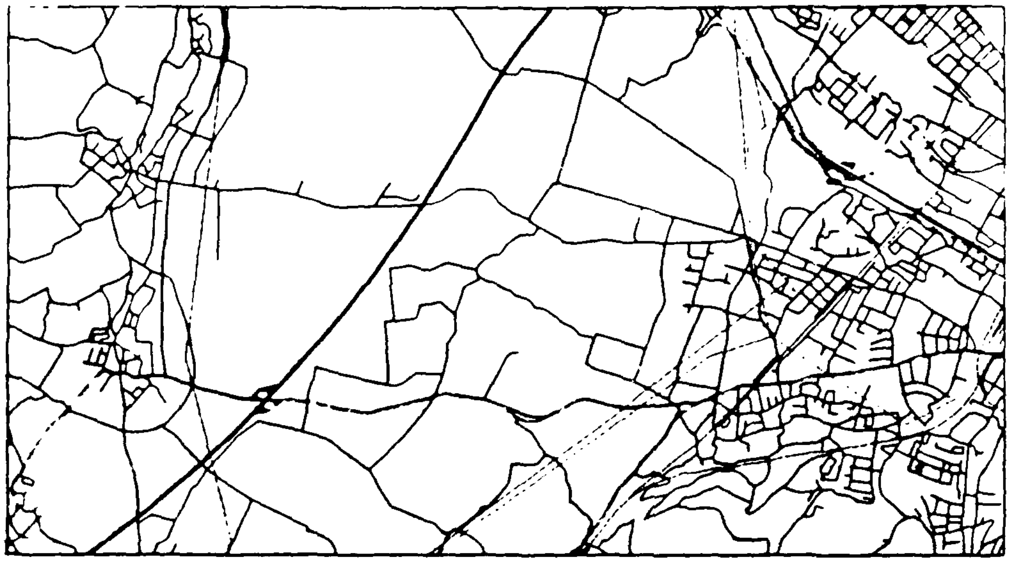

Figure 1. Freiburg Testsite Transportation Data. Linear features representing the transportation network as compiled from 1:50,000 topographic maps including autobahn, national roads, secondary roads, railroads, canals and powerlines.

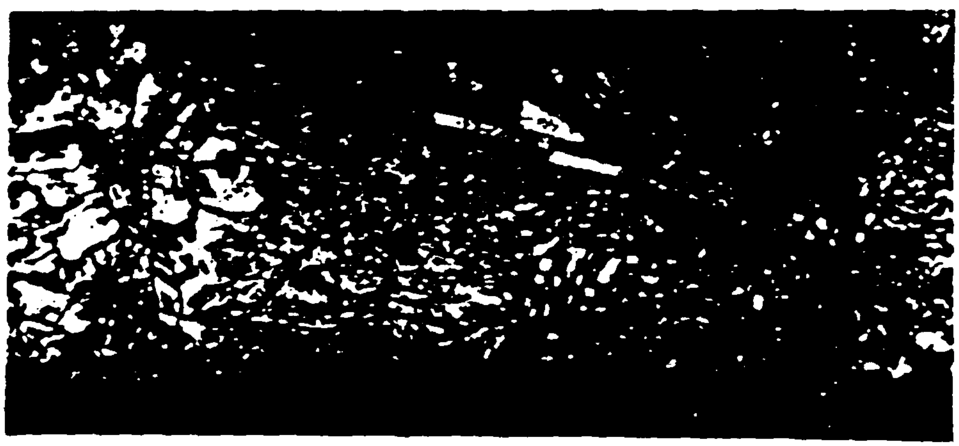

Figure 2. SAR Image with Transportation Overlay. Map-to-image correspondence was used to project transportation network onto SAR 580 radar image.

Geometric Constraints

For the digitized photography, photogrammetric procedures (8) are used to recover the acquisition parameters and map-to-image correspondence is based on the corresponding projective (collinearity) equations. Experimental radargrammetric software was modified to recover acquisition parameters of the digital SAR images by space resection (9) and the radar range equations were adapted to support SAR map-to-image correspondence. In both cases, the same general procedures are applicable whether the imagery was acquired from aircraft or spacecraft.

Explicit Knowledge Representation

The organization and maintenance of a heterogeneous knowledge base to support exploitations of a diverse set of digital map and image data via map-to-image correspondence requires flexible extensible data structures. The concept of knowledge representation using frames is well documented in the artificial intelligence literature and has been used extensively in computer vision research. For this study, a family of frame-based systems based on the FRL system developed at MIT have been designed to capture shallow, but critical, representation of knowledge concerning the digital map, terrain phenomenon, sensor and mission parameters.

Useful knowledge describing a digital map includes relevant specifications and rules used to compile the map, descriptions of the source materials and some measure of metric accuracy. In particular, it is essential to encode the terrain patterns that can be present within a mapped feature due to cartographic generalization. The German forest, for example, depicted as a homogeneous unit on a map is typically partitioned into intensively managed compartments; these compartments are linked by a network of forest roads which may or may not be encoded in the map.

For automated screening, knowledge of terrain phenomenon focuses on the phenological criteria that influence the state of a terrain pattern as a function of time. Obvious examples include state of crops in agricultural fields, canopy condition of deciduous forests and the surface state of standing water bodies.

For each sensor to be utilized, essential knowledge includes instrument calibration and performance data as well as explicit references to the appropriate processes, implemented in computer code, that model the image formation process, image illumination phenomenon and radiometric response criteria.

Mission knowledge can include descriptions of the platform, sensor suite and flight plan or mission trajectory. At a minimum, explicit representation of acquisition parameters of position, orientation and time is required for each image to be processed.

Current Status

This paper describes research in progress. The digital map and image data set described above have been installed on the Image Understanding Testbed at USAETL in conjunction with the frame-based knowledge representation system. Processed for map-to-image correspondence based on rigorous photogrammetric and radargrammetric principles have been implemented. A generate-and-test strategy has been formulated to drive a series of automated screening experiments. The approach relies on prediction of plausible signals for given map features expected to be present in a new image in the absence of significant change. Current efforts center on the implementation of a control strategy embedded within a tailored frame system and development of the specific domain knowledge bases.

CURRENT TRENDS

Issues raised in automated screening research based on map-guided scene analysis are related to a number of current trends and ongoing activities. A dramatic increase in the volume of reconnaissance imagery was cited earlier; concurrently, the Defense Mapping Agency is producing and distributing increased quantities of digital map data in the form of standard Digital Terrain Elevation Data and Digital Feature Analysis Data products for major landmasses. Specific Army initiatives in digital mapping include the development and fielding of the Digital Topographic Support System (DTSS) and the current technical base program for the Terrain Analyst Work Station (TAWS).

Related research activity is being conducted under several Defense Advanced Research Projects Agency (DARPA) programs. Significant applications of map-to-image correspondence are being explored under the Image Understanding Program with continuing efforts at Carnegie-Mellon University (10) and SRI International (5). Potential cartographic applications of image understanding techniques leading to improved interactive and partially automated systems represent a major area of interest in digital mapping research today (11).

A new DARPA program entitled Advanced Digital Radar Image Exploitation System (ADRIES) is directed to the development and demonstration of an advanced technology base for exploitation of multi-resolution SAR imagery (1). The program emphasizes largely autonomous exploitation capabilities with extensive use of collateral and contextual information to assist image analysis. Maintenance of a digital spatial model of specific geographic areas of interest and map-to-image correspondence are essential components of the program. The ADRIES program, formulated and conducted with close Army support, will lead to the development of a na-ional SAR research testbed facility at USAETL.

The DARPA Strategic Computing Program, a major national commitment to developing advanced computational capabilities, is leading to the development of novel computer architectures and processing capabilities that enable serious consideration of computationally intensive tasks such as automated screening of reconnaissance imagery. In addition, the Autonomous Land Vehicle demonstration, described elsewhere in these proceedings (6), presents challenging tasks for use of digital map data to support real-time computer vision processes as well as mission planning.

CLOSING REMARKS

The mapping and reconnaissance communities have entered an age that is data rich. In the pursuit of techniques to process abundant image data into useful information, it is important to recognize that the only common frame of reference for these dissimilar data sources is a three-dimensional model of the world with additional capabilities to record temporal change. In the past, topographers emphasized metric processing of imagery to produce accurate maps and to direct weapons systems; in other image exploitation applications, positional accuracies have been less critical -- the nearest kilometer grid cell was often close enough. Today, technical advances make it possible to extend metric fidelity to a broad range of imaging systems which will create significant opportunities for computer-assisted and automated image exploitation. The implications of this observation are clear. Optimized multisensor fusion will require analytically modeled and calibrated imaging sensors. Image acquisition parameters must be recovered routinely and made available to support image exploitation. The concept of the three-dimensional digital map must be generalized to include current situation data, analogous to the existing grease pencil overlays, to realize the potential of our mapping and reconnaissance systems to create and maintain a working model of a geographic area of interest that is current, flexible and responsive.

REFERENCES:

1. Anonymous (1985) "Advanced Digital Radar Image Exploitation System (ADRIES) Program Plan," Advanced Information & Decision Systems, Mountain View, California.

2. Anuta, P.E. (1980) "Spatial Registration of Multispectral and Multitemporal Digital Imagery Using FFT Techniques," IEEE Trans. Geosci. Electron., Vol. GE-8, No. 4, pp. 353-368.

3. Barnea, D.I. and H.F. Silverman (1982) "A Class of Algorithms for Fast Digital Image Registration," IEEE Trans. Comput., Vol. C-21, pp. 179-186.

4. Duda, R.O. and P.E. Hart (1973) Pattern Classification and Scene Analysis, John Wiley & Sons, New York,

5. Fischler, M.A. and A.J. Hanson (1983) "Image Understanding Research and Its Application to Cartography and Computer-Based Analysis of Aerial Imagery," SRI International, Menlo Park, California.

6. Leighty, R.D. and G.R. Lane (1986) "Developing Technologies for Army Autonomous Land Vehicles," 1986 Army Science Conference, West Point, New York.

7. Lukes, G.E. (1977) "Rapid Screening of Aerial Photography by OPS Analysis," Proc. SPIE, Data Extraction from Film, Vol. 117, pp. 89-97.

8. Lukes, G.E. (1981) "Computer-Assisted Photo Interpretation Research at the United States Army Engineer Topographic Laboratories (USAETL)," Proc. SPIE, Techniques and Applications of Image Understanding III, Vol. 281, pp. 85-94.

9. Lukes, G.E. and J.H. Raggam (1986) "Implementation of Map-to-Image Correspondence for Synthetic Aperture Radar Image Analysis," 52nd Annual Meeting, American Society of Photogrammetry and Remote Sensing, Washington, D.C.

10. McKeown, D.M. (1984) "Knowledge-Based Aerial Photo Interpretation," Photogrammetria, Vol. 39, pp. 91-123.

11. McKeown, D.M. and G.E. Lukes (1984) "Digital Mapping and Image Understanding," XVth International Congress of Photogrammetry and Remote Sensing, Rio de Janeiro, Brazil.

12. Norvelle, F.R. (1972) "AS-11-A Radar Program," Photogrammetric Engineering, Vol. 38, pp. 77-82.

13. Slama, C.C. (Ch. Ed.) (1980) Manual of Photogrammetry, American Society of Photogrammetry, Falls Church, Virginia.

14. Tou, J.T. and R.C. Gonzalez (1974) Pattern Recognition Principles, Addison-Wesley, Reading, Massachusetts.

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